Review of the State of Acoustic Telemetry and Constraining the Adaptation Dimension for Acoustic Telemetry Systems

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LONG-TERM GOALS

The effort has two long term goals i) assess the state of the art of acoustic telemetry systems including demonstrated experimental performance and ii) improve the performance of telemetry systems by constraining adaptation dimensions. First, the review activity aims to provide both funding managers and researchers alike an unbiased assessment of what the underwater acoustic telemetry community has accomplished. By drafting such a comprehensive research map, discussions regarding future research directions may focus on clearly identified performance deficiencies. As an example, many existing telemetry systems either neglect or only grossly account for the underlying physical mechanisms that define the channel. A prominent theme of the review thus far is that a more explicit incorporation of channel models in the design of receivers will yield improved performance. Posing and supporting assertions such as this is the fundamental objective of the review. My second set of research objectives is centered on controlling the degrees of freedom implemented in underwater acoustic telemetry receivers. Improved tap definition and placement should lead to increased levels of intersymbol interference suppression, higher channel tracking rates, and improved numerical stability in the equalizer algorithms.

OBJECTIVES

I will ascertain the state of the art in underwater acoustic telemetry to include demonstrated performance and current research trends. A comparative analysis of published work by the different groups in the community will form the foundation for a set of recommendations for future work. I will determine the level of progress in specific technology areas such as underwater networks, coding methodologies, and receiver signal processing. For the second thrust area of this work, I will establish how the time variability and spatial structure of the underwater acoustic channel may be efficiently represented, as well as exploited, in both receiver and transmitter subsystem of a complete acoustic modem. Discrete doppler effects induced by platform motion may be effectively mitigated by model-based receiver structures. The spatial character of the channel may be adaptively estimated and incorporated into both modulation strategies and the specific architecture of space-time adaptive processing algorithms.

APPROACH

The success of the review hinges on assembling a comprehensive and accurate database of previous and ongoing underwater acoustic telemetry projects. A large component of the database has come, and continues to come, from an exhaustive literature survey including both peer-reviewed journals and conference proceedings. Both I and my research assistant for this work, Mr. Daniel Kilfoyle, have

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extensive connections with the Woods Hole Oceanographic Institution as well as other organizations actively involved in this area such as the Naval Undersea Warfare Center (NUWC), Northeastern University, and the Space and Naval Warfare Systems Command (SPAWAR) which provide additional avenues for gathering information. Participation in focused review meetings provides access to unpublished research.

Efficient accommodation of underwater acoustic channels with discrete doppler components was addressed by Dr. Trym Eggen in his dissertation work. He combined a channel model with a linear equalizer. The channel model utilized a Kalman filter to recursively estimate a discrete multi-tone doppler characterization of the channel. The intent was to reduce the tracking burden on the equalizer tap weights. Mr. Daniel Kilfoyle is using a unique decomposition of the underwater channel as described by a frequency dependent modulation function to design modulation and demodulation filters for spatial taps that will result in higher throughputs and reliability for telemetry systems. The work will be experimentally validated.

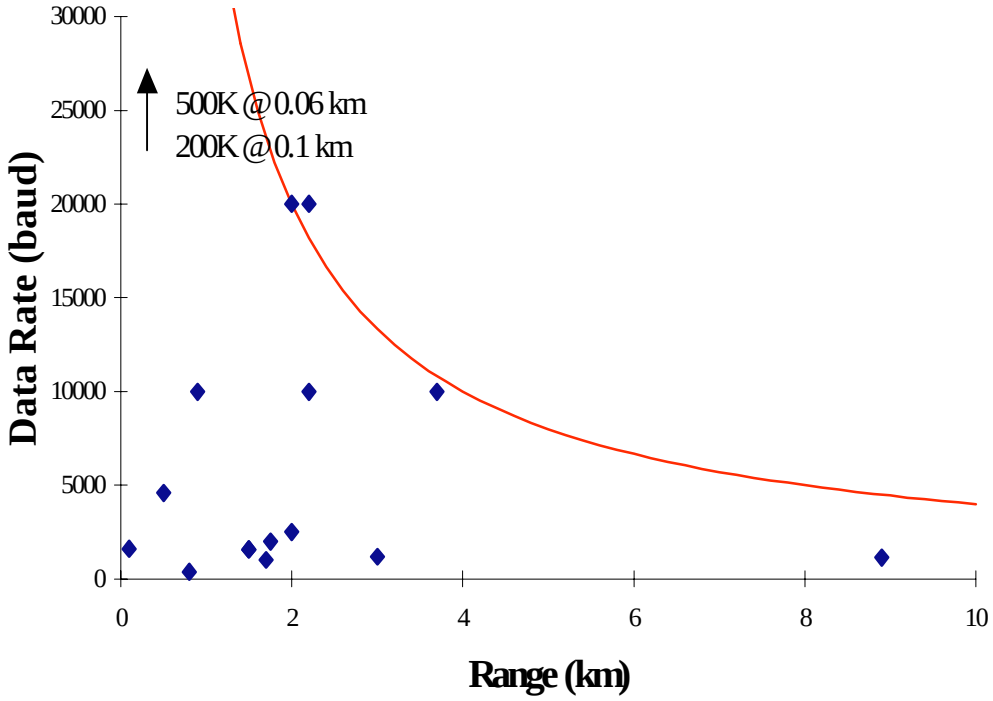
WORK COMPLETED

An electronic database of approximately 100 journal articles and conference proceedings has been assembled including a short, critical review of each by Mr. Kilfoyle.

Preliminary state of the art summaries have been presented at several public forums including the June meeting of the Acoustical Society of America in Seattle, Washington, (Baggeroer, 1998) and several ONR workshops. As an example, figure 1 depicts the range versus rate published performance of 16 underwater modems. An ad hoc upper performance bound of 40 kilometer kilobauds for the range rate product is noted.

Dr. Trym Eggen completed the development and evaluation of the multi-doppler tone coherent receiver. This is documented in his Ph.D. thesis (Eggen, 1997).

Mr. Kilfoyle developed a formalism for a spatial decomposition of the channel impulse response. An experiment was conducted near the Grand Bahama Islands demonstrating the value of spatial decomposition in a horizontal, range-azimuth plane.



RESULTS

While the *actual*

Figure 1. The published performance of 16 underwater acoustic telemetry modems along with the empirically estimated upper performance bound of 40 kilometer kilobaud for the range rate product is shown. To improve the usefulness of the comparison, only data taken in shallow water channels (< 100 m) is included.

accomplishments of the underwater acoustic telemetry community have been clearly defined through the literature survey, another import result of this year's work has been the identification of several, clear recommendations for guiding future work.

- Bridge the gap between the ocean modeling community and the signal processing community in order to spur development of modeling tools suitable for the frequencies and bandwidths of telemetry signals.
- Receiver architecture improvements should grow out of more insight into the physical ocean channel as characterized by the classical, potentially time-varying, scattering function.
- A suite of benchmark channels would be of great utility to all members of the underwater acoustic telemetry community and should be generated, initially from accurate data sets and eventually from suitable models.

A receiver appropriate for highly doppler spread environments was developed and tested upon experimental data. The results are indicated in Figure 2. The scattering function indicates a highly spread doppler path. The "eye" diagram indicates successful decoding and the decoding statistics are summarized in the figure.

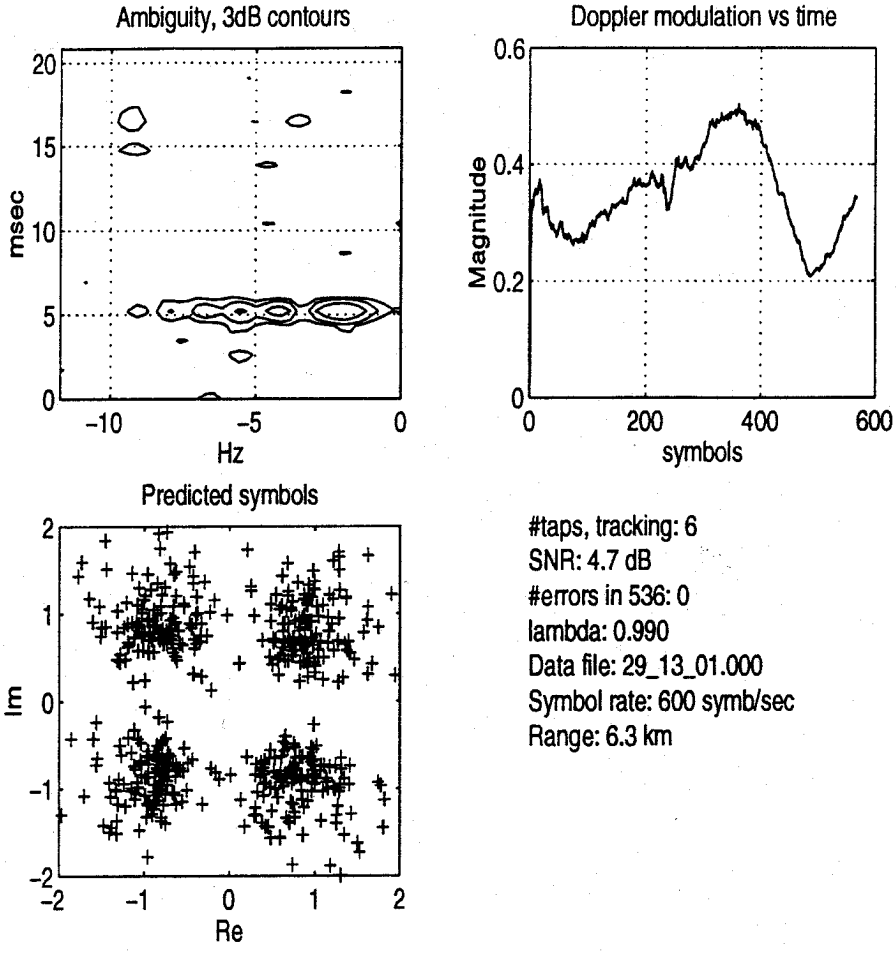


Figure 2. Decoding results for a single packet transmitted in the waters off of Gould Island, Rhode Island from a moving platform in 20 meters of water. The doppler spreading of the single arrival is clear from the ambiguity diagram. The decoding success is seen the "eye" pattern as well as the statistics.

While the theoretical basis for studying spatial degrees of freedom is still in development, the potential for increased data rates from existing AUV platform and future fixed node networks was experimentally demonstrated. Specifically, 4800 bits per second were successfully transmitted under conditions that previously only supported 2400 bits per second. This work will presented at the Acoustical Society of America conference in March, 1999.

IMPACT/APPLICATION

The state of the art summary and recommendations that arise from the review (to be published in a peer reviewed journal in 1999) should serve to guide strategic discussions of future work, specifically that funded by ONR. The work on management of degrees of freedom will lead to more robust, higher performance coherent modems for use by the U.S. Navy and oceanographic community.

TRANSITIONS

The results of the review continue to be disseminated in professional forums as well as ONR workshops. The results have also been discussed with ASTO and the review will be briefed to OPNAV-92. The multi-tone doppler receiver and spatial decomposition approaches have yet to be used in conjunction with other modem development efforts.

RELATED WORK

Mr. Kilfoyle has also been working the Mr. Lee Freitag of the Woods Hole Oceanographic Institution supporting algorithm development for the Acoustic Communications Advanced Technology Demonstration program.

PUBLICATIONS

Baggeroer, Arthur and Daniel Kilfoyle, "Telemetry and the Underwater Channel: Progress and Challenges," Proceedings of the 134th Meeting of the Acoustical Society of America, June 1998, pp. 299-300.

Eggen, Trym, "Underwater Acoustic Communication over Doppler Spread Channels," Ph.D. dissertation, Massachusetts Institute of Technology, June, 1997.